Cost-Effectiveness of Heat Pump Heating and of other Heating Systems

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Abstract: - The article analyses the cost-effectiveness of a heating system that uses a single-stage compression heat pump. The emphasis is placed on the primary energy usage in respect of annual heat needs and the specific saving assessment. In the light of economic viability assessment of different energy systems, the costs and methods of investment assessments are indicated, which make a comparison possible and furthermore identify commercial suitability of a heating system.

Key words: - Renewable energy sources, heating systems, heat pumps, primary energy, costs, cost-effectiveness

1 Introduction

The European Union (EU) energy policy is an important part of the strategy for sustainable development. The ultimate objective of the strategy paper is the security of energy supply, encompassing environmental principles. The priority of the energy supply field lies in the reduction of global atmosphere warming with emphasis on efficient energy use and on renewable energy sources (RES) [1].

As to this goal, the development and use of heat pumps in EU industrialised countries are in constant growth, as they represent the devices of the near future, especially for the purposes of heating and cooling [2, 3].

2 Heat pumps

As a heat source for the single-stage compressor heat pump system – Fig. 1 – the air, ground water, rivers, lakes, wells, industrial waste water, soil, solar energy, etc. can be used. The system is composed of a compressor, condenser, regulation valve, vaporiser, and operates on the basis of a circular process principle [4].

Fluid refrigerant in the vaporiser (e.g. R407c) after the valve pressure reduction, at low temperature and pressure, evaporates and takes on the refrigerated surroundings heat output Φ_R. Refrigerant vapours are then lead back to the compressor where they are compressed, then flowing back into the condenser they cool down to the condensing temperature and condense, and release the heat output Φ_c that is used in the heating system. The fluid refrigerant is lead from the condenser through the expansion valve where the pressure is lowered back to the vaporiser.

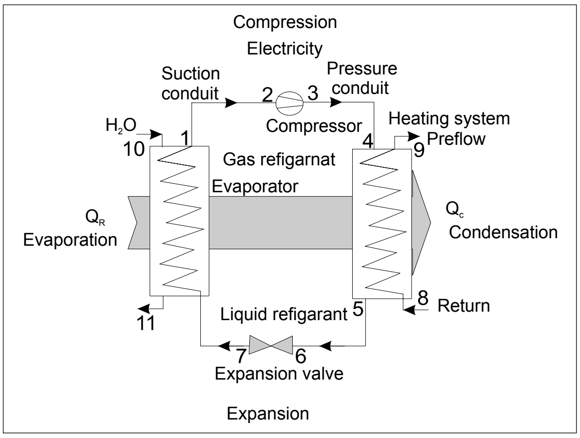

Fig. 1: Compression heat pump diagram

Compression heat pump effectiveness is defined by the heating coefficient ε_g that represents the ratio between the heating output produced Φ_c and compressor operation power consumption P [5].

$$\varepsilon_g = \frac{\Phi_c}{P} \quad (1)$$

Fig. 2 shows the annual heat pump system primary energy saving $\Delta E_p / Q_H$ and the suitability of its usage in comparison to the rest of the heating systems that are characterised by different heating systems utilisation rate.

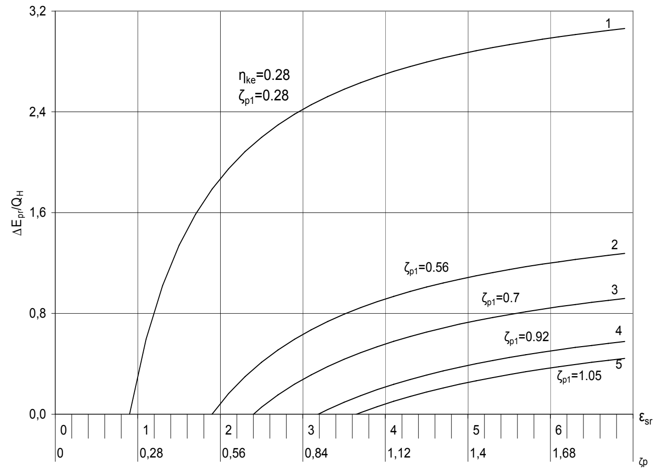

Fig. 2: Heat pump primary energy saving in comparison to:

1- Direct electrical heating,
2- Standard solid fuel boiler,
3- High-temperature boiler,
4- Low-temperature heating oil boiler,
5- Gas condenser boiler.

With the increase of value of ξ_{p1} the energy saving value decreases, when the value of the heating coefficient ε_{sr} is average.

$$\frac{d\left(\Delta E_p / Q_H\right)}{d\varepsilon_{sr}} = \frac{\varepsilon_{sr}^2}{\eta_{ke}} \tag{2}$$

The calculated results can be read from the Fig. 3. It is clear that for all $\xi_{pi} > 0$ result is the same.

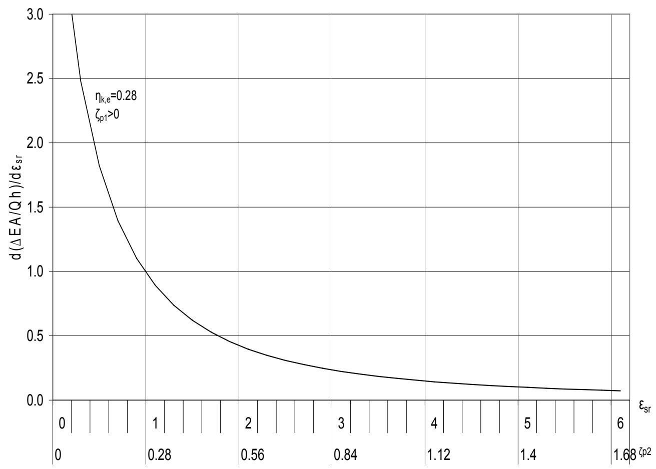

Fig. 3: Primary energy saving in relation to ε_{sr} and ξ_{p1}

3 Costs

To evaluate economic performance of the energy system, expenses have to be known, which are divided to fixed costs C_f (system implementation capital investment costs), variable costs C_{var} (system operation costs) and unexpected costs (e.g. energy price change) [6, 7].

Fixed and variable costs are combined into common costs that form a basis for the economical assessment of project alternatives.

Fixed costs consist of:

- Costs, bound directly to the annual instalment C_a, and costs that comprise:
  - Insurance costs C_z,
  - Maintainance costs C_y,
- Work costs C_d.

$$C_f = C_a + C_z + C_v + C_a + C_d \tag{3}$$

Variable costs consist of:

- Energy costs C_e (coal, electricity, oil, gas, etc.),
- Material costs (oil, lubricant, consumables),
- Services costs (costs of staff employed) C_u.

$$C_{var} = C_e + C_m + C_u \tag{4}$$

The comparison of liquid fuel heating system and heat pump variable costs for a kWh of heat can be expressed by the following equations:

$$C_{var,k} = C_g \cdot \frac{3600}{H_d \cdot \eta_k} \tag{5}$$

$$C_{var,T\check{C}} = \frac{C_e}{\varepsilon_g} = C_e \cdot \frac{T - T_0}{T \cdot \eta_{T\check{C}}} \tag{6}$$

where:

$C_{var,k}$ – alternative heating system heat price
$C_{var,T\check{C}}$ – heat pump heat price
C_g – fuel price
C_e – electricity price
$\eta_{T\check{C}}$ – heat pump utilisation rate
H_d – fuel combustion rate
η_k – boiler utilisation

Fixed investment costs and the interest rate are defined in relation to heating system operating hours with the help of Fig. 4.

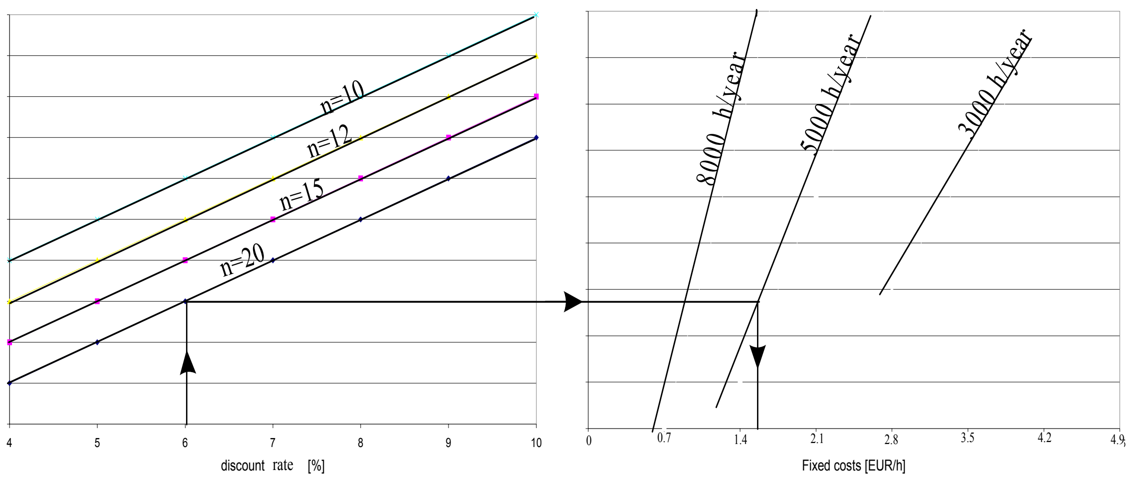

Fig. 4: Fixed costs value of 240 kW heating pump in relation with operating hour

Economic viability analysis is the first phase of the economical assessment of the project and has to include:

- Financial analysis,
- Economical analysis of the investment payback (serves as a resource investment assessment that is invested into the project or as an investment payback irrespective of the financing source).

For the viability assessment of the project investment, the following can be applied:

- Method of investment profitability level,
- Method of the payback date,
- Method of the net present value – NPV,
- Method of internal profitability level.

4 Cost-effectiveness of heat pump heating systems

4.1 The impact of heating coefficient on costs

To assess the appropriateness of a heat pump, the curve course of the annual changes of external temperatures is needed. The calculation of the heating coefficient is carried out step by step in accordance with operating conditions and the energy load. For the heat pump that uses air as its heat source and preflow temperature monitoring that is a function of external temperature, the ε_g is leaning towards the average value ε_{gsr} that is lower than the most favourable operating value.

The actual values of the heating coefficients in all the operating conditions can be read as results from Fig. 5.

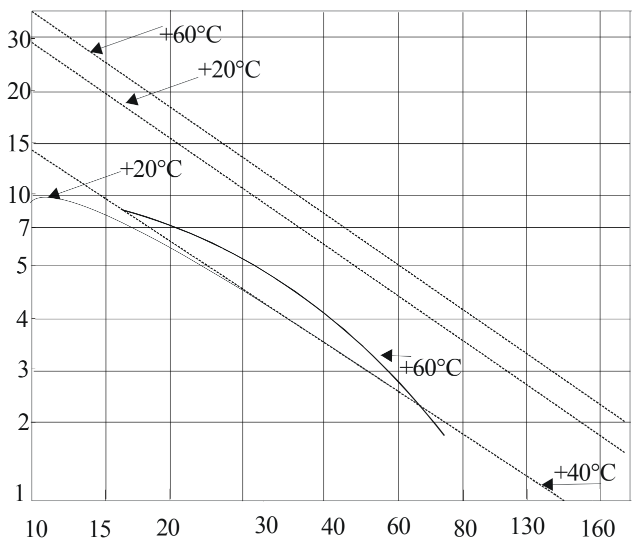

Fig. 5: Heat pump heating coefficients ε_g for:
(- - -) Carnotov's circular process,
(—) actual process, refrigerant R407c with the volumetric flow ≈ 30 m^3/h

4.2 Primary energy saving of the heating system

To define the economic viability of a heat pump heating system, the primary energy saving calculation has to be made, as well as an economical comparison with different heating systems [8]. Annual costs C are set out in this case, following the equation:

$$C = \frac{C_G \cdot k_a^n \cdot (k_a - 1)}{(k_a^n - 1)} + C_0 \cdot (k_a + 1) + C_M + C_D \qquad (7)$$

where:

C_g – construction and installation costs
C_0 – heat pump equipment costs
k_a – discount factor
C_M – maintenance costs
τ – operation time
C_D – operation costs

The annual heat energy need is determined on the basis of heat power and operation time at 100 % operation load.

To define the annual primary energy saving of the heat pump heating system compared to different heating systems, depending on the annual quantity of the heat energy ε_g and ξ_p, the diagrams were created – Fig. 6 to 7.

To assess the costs, the correct definition of operating costs share and the correct investment value assessment of the installation are crucial.

The selection of heating system depends on the cost-efficiency indicators that are based in fixed costs, variable costs and maintenance costs.

It is recommended to calculate the VDI 2067 when dealing with heating systems. If the compared systems show a great difference in variable and fixed costs, the objective comparison is difficult as the energy price change significantly affects the situation. In the past the production costs were relatively stable but recently they started to grow due to the high fuel price increase. Electricity price is growing much slower then the other energy products prices, which includes the 20 % fuel costs that are needed for electricity production.

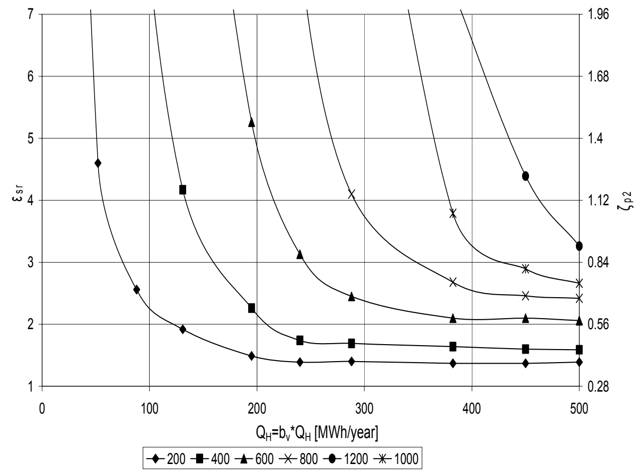

Fig. 6: Primary energy annual saving ΔE_{pr} of the heat pump system and the electricity heating system

Cost planning for energy used together with longer time span saving leads to economical calculation errors because of the possibility of energy price increase.

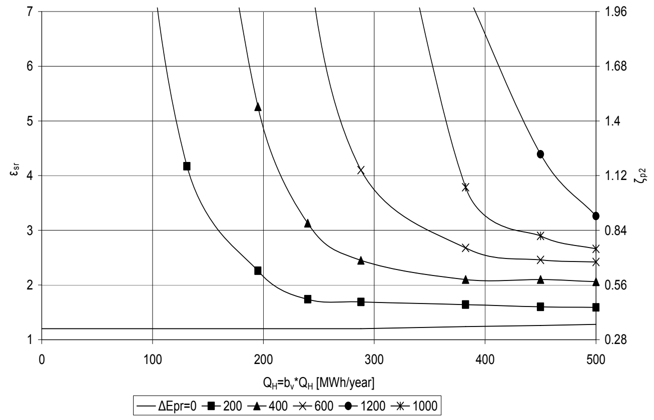

Fig. 7: Primary energy annual saving ΔE_{pr} of the heat pump system and the gas fuel heating system

Fig. 8 shows 240 kW heat pump heating system compared to the classical boiler heating system.

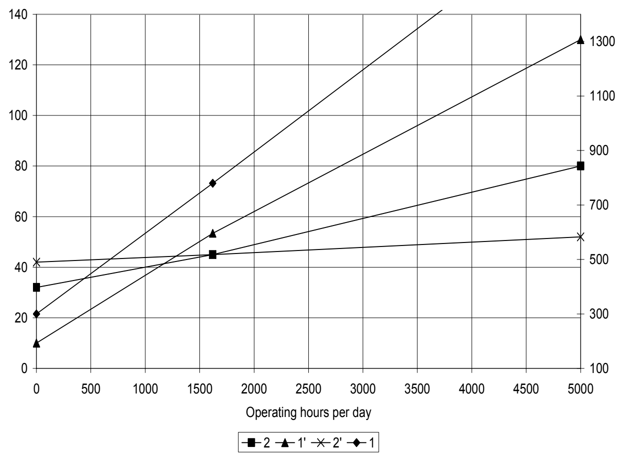

Fig. 8: Economical – energetic heating assessment in respect of operating time 1 and 1´ represent the primary energy use of the heat pump and the boiler heating systems. 2 and 2´ represent costs depending on the system – boiler or heat pump.

7 Conclusion

The heat pump heating coefficient largely depends on the operating conditions [9].

Heat pump use is economically viable when:

- The most suitable heat source can be used,
- There is a low-temperature heating regime in use,
- The system is operating for more than 2000 hours annually in full load as far as heat pump and the additional heating system is concerned in the case of increased heat loads,

- The heating coefficient value is greater than 4,
- A need of combining the refrigerating system and the low-temperature heating system exists (sport centres with ice-skating hall, fruit and vegetable storehouses, etc.).

The heat pump use is not economically viable if total load coverage is not met by the heat pump operation that operates as a heat system, if the heating coefficient reaches average value of less than 3.

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